DEVICE AND METHOD FOR MEASURING FORCES AND MOMENTS

The present invention refers to a device and to a method for measuring forces and moments.

5 In many applications (mechanical and other) it is useful to measure a force vector and a moment vector applied to a structure or a body. As an example, it could be necessary to measure the forces and moments acting between a pneumatic tire and the road surface.

10 In general, rigid objects or sensors, arranged between structures or elements that exchange forces, are used for measuring the generalised forces acting between two structures or two elements.

A drawback of such systems is the design complexity,
15 with consequent unacceptable large mass and dimensions for some applications.

The purpose of the present invention is that of realising a device and defining a method for measuring forces and moments also suitable for measuring dynamic
20 stresses.

Another purpose of the present invention is that of realising a device for measuring forces and moments that is precise and sensitive.

Another purpose of the present invention is that of
25 realising a device and defining a method for measuring forces and moments that is particularly simple and

functional, with low costs.

These purposes according to the present invention are accomplished by realising a device and defining a method for measuring forces and moments as outlined in

5   the independent claims.

Further characteristics are foresees in the dependent claims.

The characteristics and advantages of a device and method for measuring forces and moments according to

10   the present invention shall become clearer from the following description, given as an example and not limiting purposes, referring to the attached schematic drawings, in which:

- figure 1 schematically shows a first embodiment of a

15   device for measuring forces and moments according to the present invention; the device is subject to generalised forces T and F;

- figure 2 is a top view of a possible embodiment of the device of figure 1;

20 - figure 3 is a section according to the line III-III of figure 2 shown enlarged;

- figure 4 shows a connection element of spherical and sliding joint type realised by means of an elastomer element;

25 - figure 5 schematically shows another spherical and sliding joint realised through elastic elements;

- figures 5A and 5B schematically show two embodiments of a spherical and sliding joint realised through a cylindrical and a spherical bearing, the cylindrical bearing being respectively either internal with

5   respect to the spherical bearing or external;

- figures 5C and 5D schematically show another two embodiments of a spherical and sliding joint realised through a rigid sliding/spherical bearing;

- figures 6 to 8 schematically show a second embodiment

10   of a device for measuring forces and moments according to the present invention, subject to generalised forces T and F;

- figure 9 shows a further schematic embodiment of the device of figures 6-8;

15 - figure 10 is a schematic representation of an elastic Hooke's joint with bending elements, which realises an elastic connection element;

- figures 11 and 12 show a possible embodiment of the elastic Hooke's joint with bending elements of figure

20   10;

- figures 13 to 15 schematically show a further embodiment of a device for measuring forces and moments according to the present invention, subject to generalised forces T and F.

25 With reference to the figures, a device for measuring forces and moments is shown, wholly indicated with 10,

shown in three different embodiments according to the invention.

The device for measuring forces and moments comprises a measuring structure 12, made up of one or more elements and provided with a plurality of bindings, or connection elements, for the connection between the elements of the structure itself and/or a body of which one wishes to find out the forces acting on, such that the structure 12 is statically determined or else statically non-determined.

The measuring structure 12 is subject to two generalised external forces, a moment vector T and a force vector F, oriented in any way, which are the generalised external forces that one wishes to measure acting upon the body.

For such measuring structures it is possible to establish a mathematical relationship between the vector $F_g = [F_x \ F_y \ F_z \ T_x \ T_y \ T_z]$ (defined by the components along three coordinated axes of the generalised external forces F and T) and the vector $S = [S_1 \ S_2 \ S_3 \ S_4 \ S_5 \ S_6]$ of measured magnitudes in one or more points of the structure.

The measured magnitudes can be local deformations, electrical charges generated by deformations, variations in electrical resistance due to variations in local deformations, or other, and can be detected

through suitable measuring means 14 arranged on the structure 12.

In the static case such a relationship can be of the type $F_g = F_g(S)$.

5   Such a mathematical relationship can be linear, in which case the calculations to define F_g, by knowing the vector S, are relatively simple, indeed

$$F_g = C \cdot S$$

where C is an invertible square matrix of order 6.

10   In the dynamic case the mathematical relationship can be of the type

$$\dot{S} = \dot{S}(S, u)$$

$$F_g = F_g(S, u)$$

where u is a vector that represents a disturbance that

15   is variable in time. In the case in which the system is linear the dynamic equations become

$$\dot{S} = A \cdot S + B \cdot u$$

$$F_g = C' \cdot S + D \cdot u$$

where A, B, C' and D are matrices.

20   In the case of statically determined structures the matrices C, A, B, C', D mainly contain terms dependent upon the geometric dimensions of the measuring device; in the case of statically non determined structures the matrices C, A, B, C', D contain both the terms

25   dependent upon the geometric dimensions of the measuring device and the terms related to the

stiffness, in particular, of the connections (elastic joints).

Figures 1 to 3 show a first embodiment with three bindings of a device for measuring forces and moments
5   10 according to the present invention, in particularly suitable, amongst other things, for being mounted on the hub of a wheel, not shown, to measure the generalised forces acting on the wheel itself.

The device comprises the measuring structures 12
10   configured with three arms 15, for example arranged at 120°, carrying at the end 16 the connection elements or bindings consisting of three spherical joints 17, which are free to translate in the direction of the axis of the arms 15 thanks to the sliding type constraint 18
15   realised through a sleeve. In figures 1 to 3, as an example, the straight arms 15 are shown, but of course the measuring structure 12 can consist of an element having three arms 15 with more complex shape.

With the constraints consisting of spherical joints 17
20   and sliding elements 18 each arm 15 of the structure 12 is subject to two bending moments acting orthogonally. The two bending stresses, which are generated by the aforementioned two perpendicular bending moments, can be measured by two pairs of strain gauges 14a and 14b
25   as shown in figures 2 and 3, which constitute an example of possible measuring means.

In a first embodiment, shown schematically in figure 2
in a partial section view, the bindings arranged at the
end of the arms 15, in other words the spherical joints
17 with sliders 18, can be realised through rigid

5   elements. For example, the constraint 17 can be
realised through spherical joints, self-aligning ball
bearings or else radial ball bearings equipped with
suitable axial clearance. The sleeve 18, acting at each
spherical joint 17, can for example be realised through

10   a plain bearing, a ball-circulation sleeve or else a
sleeve with balls and/or rollers.

Alternatively or in combination with the aforementioned
rigid connection elements, elastic elements can be used
with suitably defined characteristics to avoid the

15   introduction of significant errors in the measurement
of the generalised forces T and F. For example, the
connection element according to one of the axes x
and/or y and/or z can be an elastic support that is
very rigid in the radial direction and very flexible in

20   the other directions. For example, figure 4 shows, in a
partial section view, an elastic spherical joint and
elastic slider type constraint realised with an element
made from elastomer 19, the shape of which can be
different with respect to the one shown, inserted in

25   two external cylinders 20, for example made from metal,
inside which the end 16 of each arm 15 of the measuring

structure 12, only partially shown, is inserted, which is thus subjected to an axially yielding and radially rigid constraint.

Figure 5, on the other hand, schematically shows a further example of an elastic spherical joint 17 and elastic slider 18 type binding, comprising an elastic Hooke's joint 21 equipped with bushings with zero clearance and friction 23, arranged in series with an elastic cylindrical hinge 22 consisting of a further bushing with zero clearance and friction 23, so as to realise a spherical joint 17 with practically zero clearance and friction. A thin plate with four fixed ends 24 is placed in series with the spherical hinge 17 realising a slider 18 type constraint since it is axially yielding due to its elasticity.

The bushings 23 with practically zero clearance and friction can, for example, be realised with one or more thin plates subject to bending moment arranged inside the bushing themselves, not shown, purely as an example of the type of those produced by the company C-Flex Bearing Co., Inc., FRANKFORT, NY 13340 USA.

Figures 5A and 5B schematically show two embodiments of rigid spherical joint 17 and slider 18 type binding. In figure 5A the cylindrical plane bearing 18 is between the end 16 of the arm 15 and the spherical joint 17. In figure 5B the spherical joint 17 is between the end 16

of the arm 15 and the cylindrical plane bearing 18.

Figures 5C and 5D schematically show other two
embodiments of rigid spherical joint 17 and slider 18
type binding. In figure 5C the convex surface of the

5 spherical joint 17 acts directly on the cylindrical
surface of the plane bearing 18. In figure 5D the
convex surface of the spherical joint 17 acts directly
on the cylindrical surface of the housing that has the
function of the plane bearing 18. Figures 5C e 5D

10 schematically show a sphere, or a convex element,
sliding into a cylinder.

To measure the generalised forces acting along axes
passing through a point of a generic body, therefore,
the measuring structure 12 of the device for measuring

15 forces and moments 10 according to the invention that
comprises the three arms 15 is suitably bound with such
a body. The bindings arranged at the ends of the arms
are of the spherical joint 17 and slider 18 type, rigid
or elastic, and they allow a statically determined or

20 statically non determined structure to be obtained.
From the six measurements of the perpendicular bending
moments that act along the length of each arm 15, for
example obtained through strain gauges 14, a force
vector F, splitted into three vectors directed along

25 three coordinated axes, and a moment vector M, splitted
into three vectors directed along three coordinated

axes, can be measured.

Figures 6 to 8 show a second embodiment with six bindings of the device for measuring forces and moments 10' according to the present invention, in which the

5   measuring structure 12 is made up of two triangular rigid elements, an upper plate 25 and a lower plate 26, bound together at the respective three vertices 25A, 25B, 25C, 26d, 26e and 26f through two connecting rods 27 for each vertex. The two connecting rods link two

10 contiguous vertices of the opposite triangle. As shown in the drawings from 6 to 8 the connecting rods 27Ad and 27Af link the vertex 25A of the upper triangle with the two contiguous vertices 26d and 26f of the lower triangle 26.

15 With respect to that which has been shown schematically in the figures, the triangular rigid elements 25 and 26 can have a more complex shape, just as the connecting rods 27 can be lengthened or shorted and arranged spatially with different proportions with respect to

20 that which has been illustrated.

The connection elements at the ends of the connecting rods 27 are realised through spherical joints or spherical hinges 17, or rather elastic elements made from elastomer that can be modelled by means of

25 spherical joints with low stiffness in rotation. The structure described here in which the rigid triangular

elements 25 and 26 are connected through three statically determined triangles realised through connecting rods 27 is known by the name "hexapod reticular structure".

5   One of the rigid plates, for example the lower plate 26., is rigidly connected to a body 11, of which one wishes to measure the stress, as shown schematically in the figures, in which the active external forces are schematically indicated, decomposed on three

10   coordinated axes.

Each connecting rod 27, being subject to axial force, apart from approximations that lead to insignificant errors, can be used to measure the traction or compression force acting on it. Knowing the forces that

15   are therefore exclusively axial or about axial acting on each connecting rod, from the balance of the upper triangle 25 or lower triangle 26 it is possible to derive the acting external forces.

Through the relationship introduced previously $F_g = C \cdot S$

20   the relationship between the measurement vector S and the acting generalised forces is established.

A further embodiment of the device for measuring forces and moments 10'' according to the present invention, similar to the device 10' described previously, is

25   shown in figure 9. The connecting rods 27 are connected to the triangular rigid elements 25 and 26 through

11

spherical joints 17 that are distinct and do not coincide like in figure 6, providing greater simplicity of design of the joints themselves.

As already described previously for the arms of the
5   measuring structure, the bindings at the end of the connecting rods can also be realised through rigid elements or else through elastic elements.

For example, the constraints 17 can be realised through spherical joints, self-aligning ball bearings or else
10   radial ball bearings designed with suitable clearance.

Alternatively or in combination with the aforementioned rigid connection elements, elastic elements can be used with suitably defined characteristics to avoid the introduction of significant errors in the measurement
15   of the generalised forces T and F.

For example, the elastic Hooke's joint 21 arranged in series with the elastic cylindrical hinge 22, which in figure 5 are shown coupled in addition to a thin plate sheet 24, represent a possible embodiment of an elastic
20   spherical joint 17.

In the case in which the forces acting on the connecting rods 27 are substantially always traction forces, the elastic Hooke's joint shown in figure 5 could be replaced with the elastic Hooke's joint with
25   bending elements 28 shown schematically in figure 10 and according to a possible non-limiting example

embodiment in figures 11 and 12.

The opposite parts to be connected 29 through Hooke's joint with bending elements 28 terminate with a fork element 30, as shown in figure 12, and can be
5   connected, for example through bolts, respectively to two pairs of thin plates 31 and 32 that realise the joint according to two perpendicular planes. Indeed, at their opposite ends the thin plates 31 and 32 are bound to a cross element 33 consisting of two perpendicular
10 elements 34 jointed by a spacing cross member 35.

The elastic Hooke's joint with bending elements 28 has the advantage of being a system that, in the case of small deformations, allows the typical behaviour of a Hooke's joint with practically zero friction and
15 clearance to be obtained. The elastic Hooke's joint with bending elements can be used in the device for measuring forces and moments, subject of the present invention as well as in other devices in which it is necessary to have, for rotations of a few degrees, a
20 double hinge with perpendicular axes and practically zero friction and clearance.

Finally, a further embodiment of the device for measuring forces and moments 10''' with three bindings according to the present invention is shown
25 schematically in figures 13 to 15.

The measuring structure 12, on which the active

external generalised forces are shown schematically, is
constructed by means of two triangular rigid elements,
an upper plate 25 and a lower plate 26, linked together
at the respective three vertices 25A, 25B, 25C, 26d,

5   26e and 26f through three shell elements 36,
substantially triangular in shape, which in the figures
are shown as flat, just as an example.

The elements 36Adf, 36Bde and 36Cef, shown in the
figures, are connected to the lower element 26 through

10 a hinge 37 type binding and to the upper element 25
through a spherical joint 17.

The rigid triangular elements 25 and 26 are thus
connected through the three shell elements 36 bound in
a statically determined way; each element 36 is subject

15 to bending moment and to axial action and can be used
to measure the forces acting on the device.

Indeed, knowing the stresses acting on each element 36,
which can for example be measured through strain gauges
according to that which has been illustrated, from the

20 equilibrium of the upper triangle 25 or lower triangle
26 the acting external generalised forces can be worked
out through the relationship introduced previously $F_g = c \cdot s$.

The bindings 17 and 37 shown schematically in the

25 figures can be realised through rigid elements, as well
as through elastic elements.

For example, the constraint 17 can be realised through spherical joints, self-aligning ball bearings or else radial ball bearings manufactured with suitable axial clearance.

5   The binding 37 can, for example, be realised by suitably combining plain bearings, radial ball bearings or else a sleeve with balls and/or rollers.

Alternatively or in combination with the aforementioned rigid connection elements, elastic elements can be used

10 with suitably defined characteristics to avoid the introduction of significant errors in the measurement of the generalised forces T and F.

The device and method for measuring forces and moments object of the present invention has the advantage of

15 being easily adaptable for measuring the forces acting on different types of bodies.

The device and method for measuring forces and moments object of the present invention has the advantage of being constructively simple and robust. Since the

20 measuring device is mounted in a substantially statically determined way (when the assembly is statically non determined the effects coming from statically non determined assembly are controlled and of minimal influence because the stiffness of the

25 connections is always predefined, so being relatively low, the yield of the bindings will have little

influence on the measurement, a fact that cannot be ensured with other known systems, mounted in a highly statically non determined manner.

The device for measuring forces and moments thus
5   conceived is susceptible to numerous modifications and variants, all of which are covered by the invention; moreover, all of the details can be replaced with technically equivalent elements. In practice, the materials used, as well as the sizes, can be whatever
10 according to the technical requirements.